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EXPLORING IN AEROSPACE ROCKETRY
10. SPACE MISSIONS

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Presented to Lewis Aerospace Explorers
Cleveland, Ohio
1966-67

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10. SPACE MISSIONS

Richard J. Weber*

FLIGHT PATHS

To serve as a foundation for the understanding of space missions, it is helpful first to consider the characteristic flight paths of spacecraft. It has already been explained in chapter 9 that if an object is given a sufficiently high horizontal velocity, it will not fall back to Earth. Instead it will continue to "fall" around the Earth in a circular path (provided that the altitude is high enough so that atmospheric drag does not cause it to lose energy and descend). When the object is thus in a circular orbit (path A in fig. 10-1), its

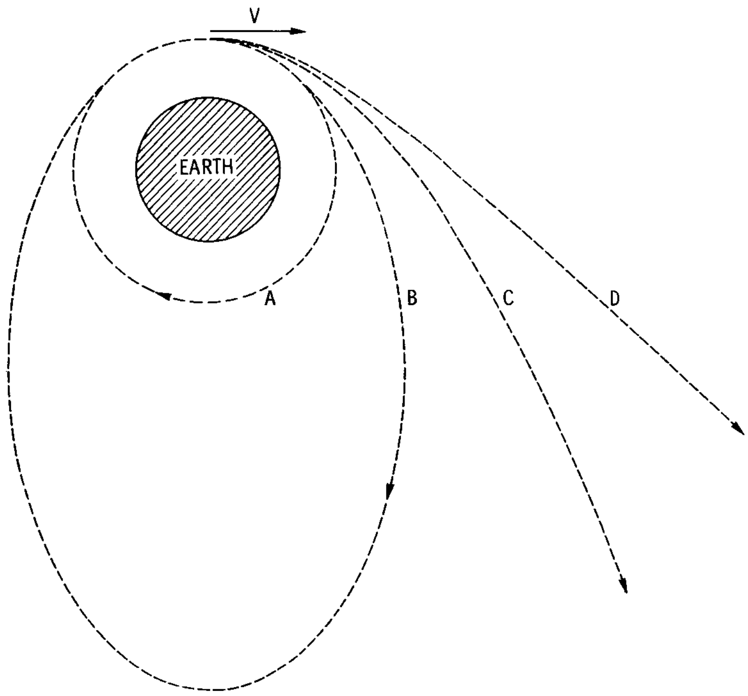

Figure 10-1. - Changes in flight path caused by changes in initial velocity.

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velocity is such that the centrifugal force just equals the gravitational attraction:

$$\frac{V_c^2}{R} = g_0 \frac{R_0^2}{R^2}$$

$$V_c = \sqrt{\frac{g_0 R_0^2}{R}} \approx \sqrt{32.2 \times 4000 \times 5280} \approx 26\ 000 \text{ ft/sec}$$

where V_c is the circular-orbit velocity, R is the radius of the orbit, R_0 is the radius of the Earth, and g_0 is the acceleration due to gravity at the Earth's surface.

If the initial velocity of the object is greater than V_c, the orbital path is an ellipse (path B in fig. 10-1). With further increases in initial velocity, the apogee of this elliptic orbit is moved farther away from the Earth. In the limit, the distance of the apogee from the Earth is infinity, the ellipse changes into a parabola (path C in fig. 10-1), and the object travels so far away from the Earth that it "escapes" from the Earth's gravitational attraction and does not return. The initial velocity required for the object to just barely escape in this fashion can be determined by using calculus. The approximate value of this escape velocity V_{esc} is

$$V_{esc} = \sqrt{2}\, V_c \approx 36\ 000 \text{ ft/sec}$$

An object with this initial velocity will coast away from Earth at gradually decreasing speed until it finally reaches a very great distance from Earth at zero speed. The zero speed is relative to the Earth; since the Earth itself is moving around the Sun, the object will also be moving around the Sun in a circular orbit, just like a planet.

If the initial velocity of the object is greater than the escape velocity, then the trajectory of the object relative to Earth is a hyperbola (path D in fig. 10-1). After the object has coasted a great distance away from Earth, it still has some excess velocity. Hence, instead of going into a circular orbit around the Sun, the object enters an elliptic orbit, as shown in figure 10-2. With each additional increase in initial velocity, the apogee of this elliptic orbit is displaced farther from the Sun, and the orbit may intersect the orbits of other planets (fig. 10-3). An interplanetary transfer mission can be accomplished by aiming the trajectory and timing the launch so that the object and the other planet arrive simultaneously at the point of intersection of their orbits.

Note that all the space trajectories discussed herein are simple conic sections (circles, ellipses, parabolas, hyperbolas) and that the flights consist primarily of coast paths only. Rockets are needed only to give the necessary velocity at the beginning of

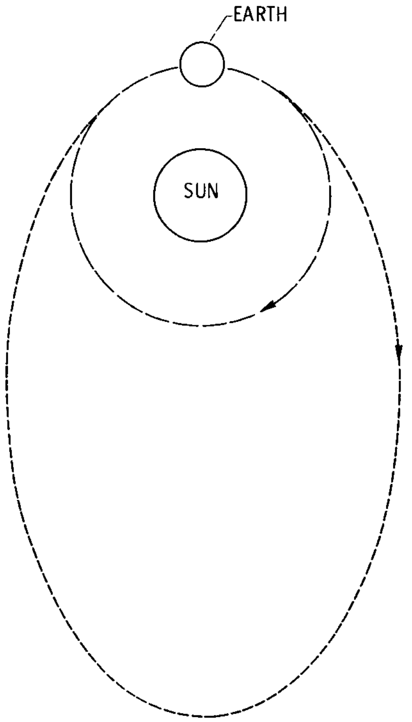

Figure 10-2. - Excess energy yields elliptic orbit about the Sun.

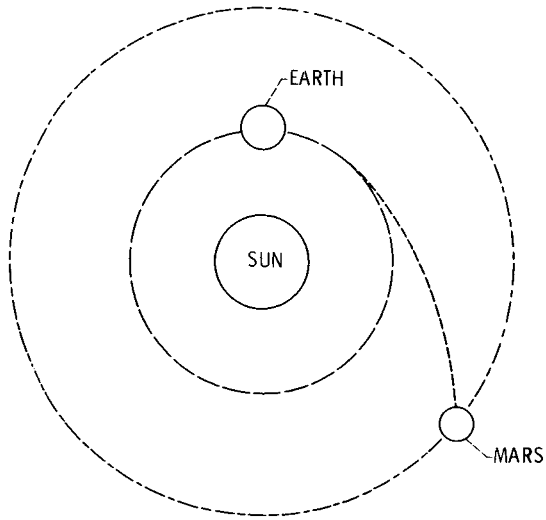

Figure 10-3. - Proper elliptic path intercepts planet.

the flight (or at the end if we wish to slow down). (An exception to this simple condition is discussed in chapter 20, which concerns the use of electric propulsion.)

For real missions, of course, the analyses of trajectories are complicated by such factors as the orbits and orbital planes of other planets, the timing of the launch, the direction of the launch, the duration of the mission, etc. However, the basic concepts used in these analyses are the simple ones which have been described herein.

MISSION OBJECTIVES

A space mission essentially consists of a spacecraft traveling along a trajectory and carrying equipment to accomplish a particular job. A mission normally has one "direct" objective, and it may also have one or more "indirect" objectives. Some of the most common mission objectives are presented in the following list:

(1) Direct
- (a) Application (weather study, communication, navigation)
- (b) Science (measurement of environmental conditions)
- (c) Engineering (development and testing of equipment)
- (d) Exploration

(2) Indirect

(a) Prestige

(b) Military value

(c) Technological advancement

(d) Stimulation of national economy

(e) Alternative to war

The mission objective determines the destination of the spacecraft and the mission profile (the general way the mission is to be carried out). Destination and profile constitute the mission type. The following are the various mission types:

(1) Destination

(a) Near-Earth

(b) Lunar

(c) Planetary

(d) Other (solar, extra-ecliptic, asteroidal, solar escape)

(2) Profile

(a) Unmanned; manned

(b) One-way; round trip

(c) Flyby; gravitational capture (orbit); landing

(d) Direct departure from Earth's surface; departure from Earth's surface by way of Earth parking orbit

SOUNDING ROCKETS

Sounding rockets are of particular interest because model rockets are more similar to them than to other full-size rockets. "Sounding" is the measurement of atmospheric conditions at various altitudes. A sounding rocket is relatively small. It is fired vertically, and without sufficient energy to place it into orbit or to cause it to escape Earth's gravitational attraction. For the purpose of obtaining atmospheric data, a sounding rocket has the following advantages over other devices:

(1) A rocket can obtain data at altitudes higher than that of a balloon (30 km) but lower than that of a satellite (200 km). Many important phenomena occur in this altitude region. Most of the radiation approaching Earth (X-rays, ultraviolet rays, energetic particles) is absorbed here, airglow and aurorae occur, meteoroids burn up, transition occurs between nonionized and ionized regions, etc.

(2) Even at high altitudes, a rocket is superior to a satellite for determining vertical variations and for reaching a preselected point at a particular instant.

(3) In general, a rocket is more flexible than a satellite in terms of operation and payload. Also, the rocket has a much lower initial cost.

The major disadvantage of a sounding rocket is its very limited lifetime; it is therefore expensive in terms of cost per unit of information obtained. Nevertheless, sounding rockets have been used extensively in the past and will, no doubt, continue to be used in the future.

MISSION PAYLOADS

Once the mission objective is specified, the payload (equipment, power supply, etc.) necessary to accomplish the mission must be selected. In many cases the payload must be made smaller than is really desired, just because the available rocket launcher is limited in its capability. The following are two examples of typical mission payloads.

Mariner IV

The Mariner IV spacecraft (fig. 10-4) was designed to make scientific measurements about the planet Mars. It was launched by an Atlas-Agena booster on November 28, 1964 and passed Mars on a flyby trajectory on July 14, 1965. During this time it traveled 325 million miles on an elliptical path that missed Mars by only 6118 miles. Figure 10-5 shows one of the pictures of Mars it took. The true payload of the spaceccraft consisted of the scientific instruments listed in table 10-I. The combined weight of these instruments was only 35 pounds. But other items which had to be added to this payload included

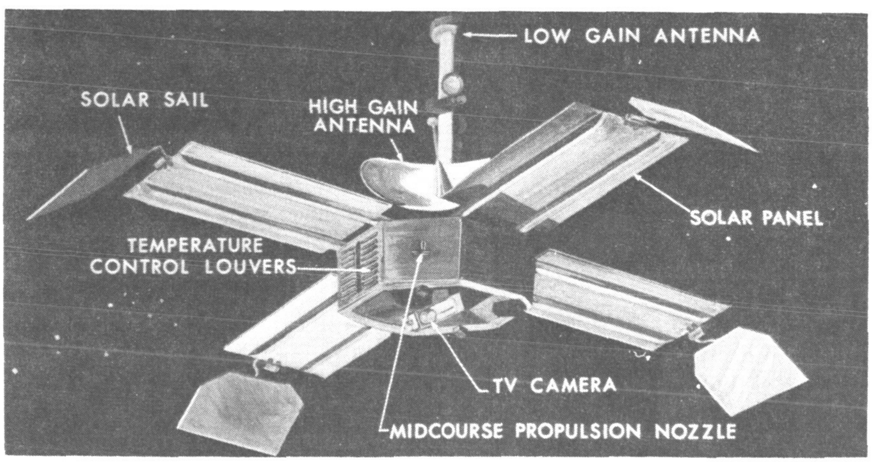

Figure 10-4. - Mariner IV spacecraft. Mission, Mars flyby; weight, about 570 pounds; launch vehicle, Atlas Agena.

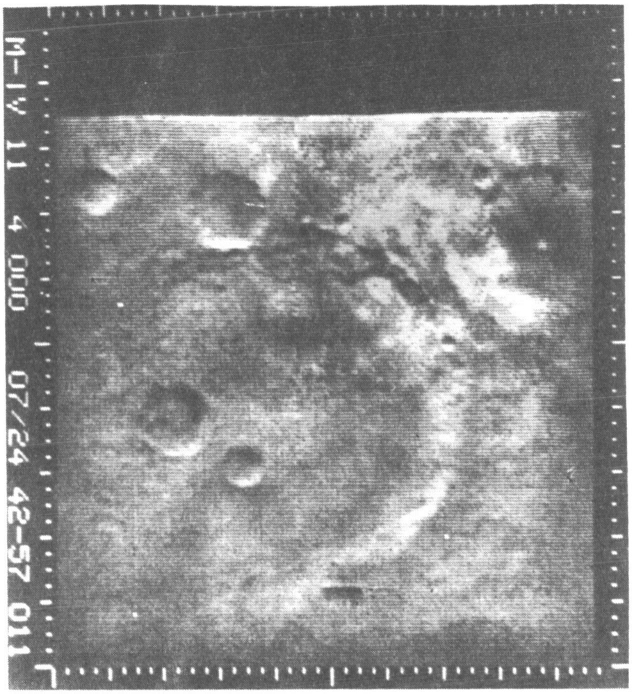

Figure 10-5. - Photograph of planet Mars taken by Mariner IV spacecraft.

TABLE 10-I. - MARINER IV SCIENTIFIC INSTRUMENTS

Description	Weight, lb	Power requirement, W
Cosmic-ray telescope	2.58	0.60
Cosmic-dust detector	2.10	.20
Trapped-radiation detector	2.20	.35
Ionization chamber	2.71	.46
Plasma probe	6.41	2.90
Helium magnetometer	7.50	7.30
Television	11.28	8.00

a radio to receive commands from Earth and to send back data, solar panels to provide electrical power for the instruments and radio, louvers for thermal control, propulsion for attitude control and midcourse guidance, structure to hold all the pieces together, etc. The weight of all this additional equipment was 535 pounds. Thus, although the true payload was only 35 pounds, the actual total payload which had to be launched into space was 570 pounds. This Mariner payload is typical of current unmanned, scientific flyby probes.

Manned Mars Vehicle

As an example of a very different type of vehicle payload, let us examine what might be required for a manned Mars landing mission. The true payload in this case will be the crew of perhaps seven men plus whatever samples of Mars they try to bring back. The weight of the men and the samples would only be about 2000 pounds. But as far as the spaceship is concerned, this basic payload must be increased by all the equipment and supplies necessary to keep the crew alive during their journey. As shown in figure 10-6, it is convenient to divide this total payload into two parts. One part will be carried all the way to Mars and back again to Earth, whereas the other part is no longer needed after Mars is reached and so can be discarded there in order to lighten the spaceship.

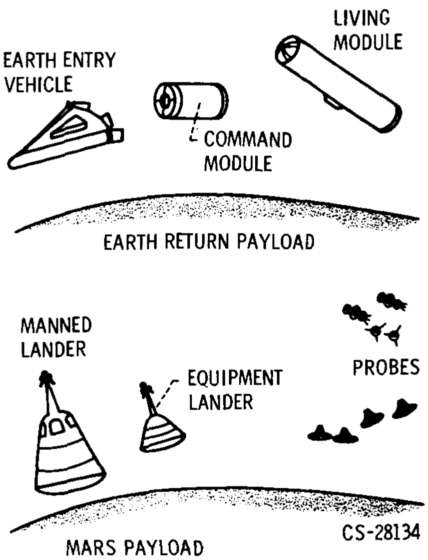

Figure 10-6. - Payloads for interplanetary vehicle.

In the particular study quoted here, the round-trip payload consists of a command module, a living module, and a lifting reentry vehicle to return the crew to the surface of the Earth; the total weight of this payload is estimated to be 80 000 pounds. Additional equipment to be expended at Mars includes Apollo-type landing capsules and assorted orbital probes; the weight of this additional equipment is also approximately 80 000 pounds.

ANALYSIS OF TYPICAL MISSION

Even a brief analysis of a manned interplanetary mission reveals the great complexity of such a mission and the vast amount of planning required. As a typical example, let us consider a mission with the specific objective of landing men on the surface of Mars for 40 days of exploration and then returning them to Earth. Theoretically, there are many ways of accomplishing this mission. The following is a breakdown of one reasonable method:

(1) Various components of the interplanetary spacecraft are launched individually by Saturn V boosters into a parking orbit around the Earth. Then, from these components, the spacecraft is assembled in orbit.

(2) The assembled spacecraft is injected into an elliptic trajectory toward Mars. Nuclear rocket engines and hydrogen fuel are used for this phase of the mission.

(3) After the spacecraft has coasted for 260 days, it is decelerated by nuclear rockets into a parking orbit around Mars.

(4) From this parking orbit, some of the crew members descend to the surface of the planet by means of Apollo-type landing capsules.

(5) After the men have completed their 40 days of exploration, they return to the orbiting spacecraft by means of the landing capsules. Chemical rocket propulsion is used for this part of the mission.

(6) Nuclear rockets are used again to inject the spacecraft into an elliptic path toward Earth.

(7) After the spacecraft has coasted for 200 days, the crew transfers to an atmospheric entry vehicle. Chemical rockets are used to slow down this vehicle to a velocity of 50 000 feet per second. As the vehicle enters the Earth's atmosphere, it is slowed further by air drag. Finally, the vehicle glides to a landing on Earth. The trip has lasted a total of 500 days.

The preceding example is just one, arbitrarily chosen method out of many, theoretically possible ways of accomplishing the Mars mission. Many alternative methods will have to be analyzed thoroughly before the best one can be selected for the actual mission.

Many of the factors that must be studied and analyzed are related to the trajectory of the spacecraft. For instance, the flight duration is very important. Fast trips require more fuel, while slow trips require more life-support supplies and equipment. Also, slow trips are more harmful to the crew because the men are exposed to more cosmic rays and solar flares, their muscles deteriorate from zero gravity, they become homesick, etc. If the flight path approaches too close to the Sun, the effect of solar-flare radiation is intensified. If the velocity in returning to Earth is too high, the entry vehicle may burn up like a meteor.

In picking the propulsion system there are also many alternatives. Chemical rockets are very light but use up much fuel. Nuclear rockets are much more efficient but are heavier and produce dangerous radiation. Hydrogen fuel is light but boils away unless the temperature is less than -423° F.

With so many alternatives (of which these have been but a few examples), it is not surprising that there is great controversy about the best way to carry out the mission. Many engineers and scientists are now studying the problem so that a logical choice may be made in the future. One possible design for the spaceship is shown in figure 10-7. The weight of this ship in Earth orbit would be about 2 million pounds. A booster rocket large enough to launch this spaceship directly from the ground would weigh about 40 million pounds (more than six times the weight of the Saturn V rocket). Special maneuvers and/or design techniques which may make it possible to reduce these weights include (1) using fuel for radiation shielding of the crew, (2) atmospheric braking at Mars, (3) midcourse thrusting, (4) Venus swingby, and (5) dividing the payload into manned and unmanned parts that are transported by separate vehicles traveling on dissimilar trajectories.

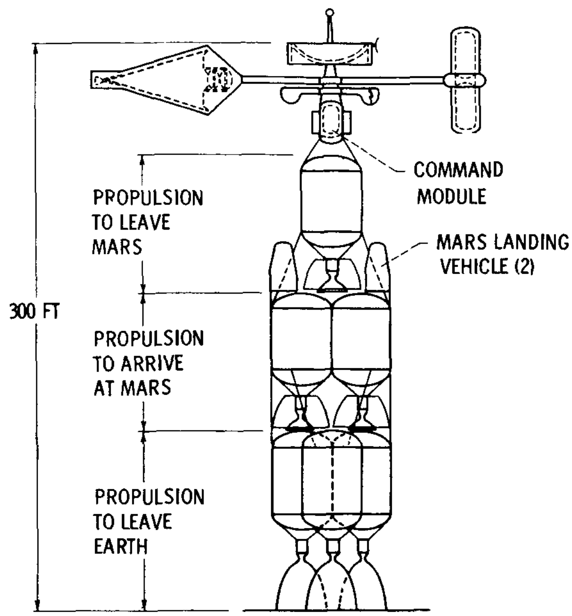

Figure 10-7. - Assembled Mars space vehicle in Earth orbit. Earth return mission payloads shown deployed for space flight.

Obviously, the planning and execution of a space mission, particularly a manned mission, require the work of experts from almost every branch of engineering. Some examples of these branches are trajectory analysis, life support systems, radiation shielding, structural design, heat transfer, aerodynamics and fluid flow, instruments and radio, and propulsion systems.

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